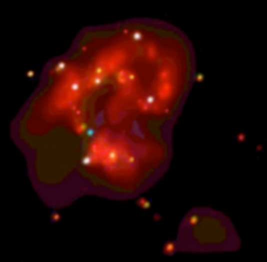
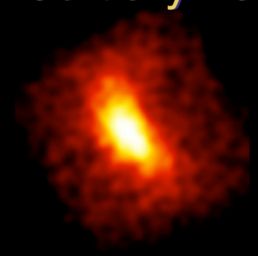
Constellation X

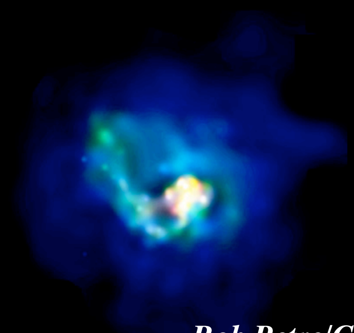
The Constellation X-ray Mission

Spectroscopy X-ray Telescope (SXT) Mirror

February 15, 2005







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Outline

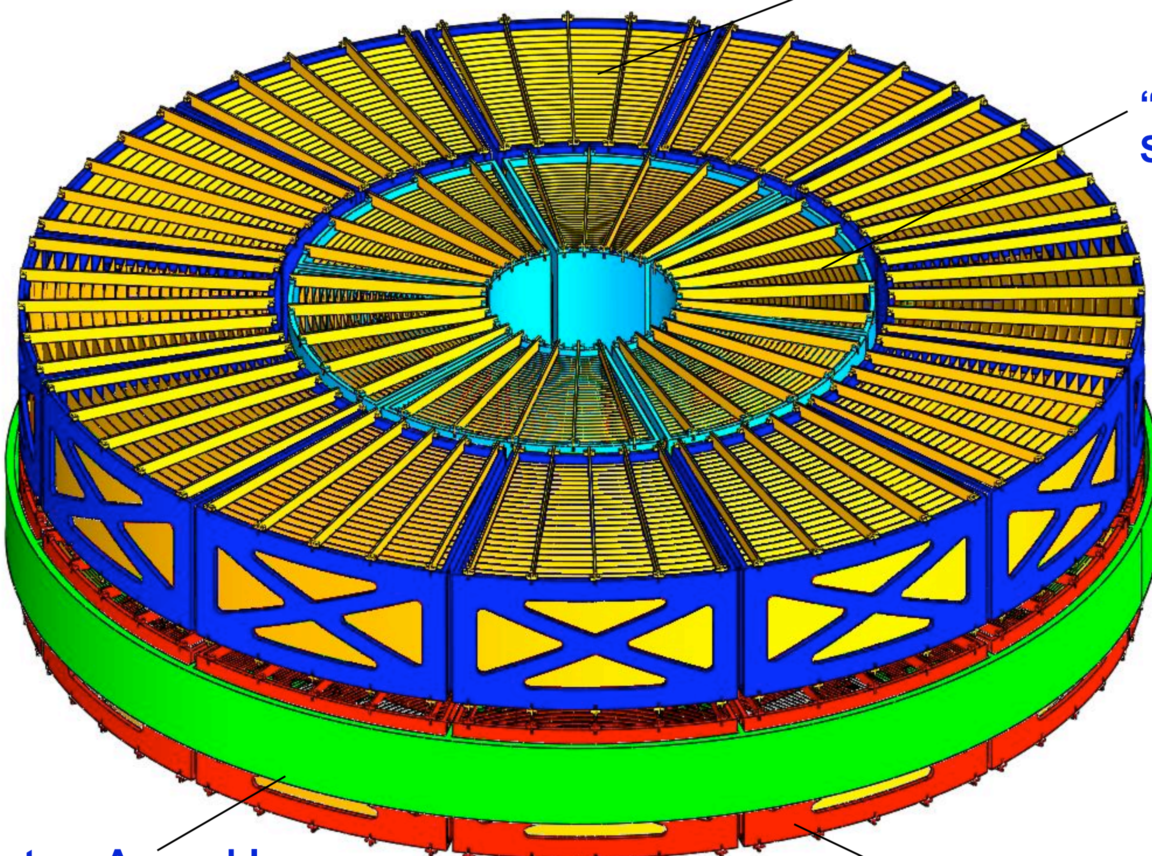
- **Overview - Status & Plans (R. Petre)**
- **Mirror Segment Fabrication (W. Zhang)**
- **Alignment and X-ray Test Preparations (S. Owens)**

SXT Flight Mirror Assembly Requirements (per mirror)

SXT FMA Performance Requirements		Trace to Top-Level Mission Requirements
Bandpass	0.25 to 10 keV	Allocation of mission bandpass to SXT
Effective area allocation @0.25 keV @1.25 keV @6 keV	 7,025 cm^2 6,797 cm^2 1,830 cm^2	Includes estimates for structural blockage and optical losses. Allocation changed from TRIP due to higher throughput from off-plane gratings , providing more margin on effective area of the telescope system
Angular resolution	12.5 arcsec HPD	Error budget allocation to mirror that allows telescope system to achieve requirement of 15 arcsec with 4 arcsec margin combined by RSS .
Field of view	2.5 arcmin	Defined by detector field of view (FOV)
Derived Requirements: SXT Mirror		**Derivation**
Diameter	1.6 m	To meet mission area requirements with 4 mirrors
Focal length	10 m.	Consistent with grazing angle requirements for 1.6 m diameter mirror.
Axial length	<70 cm	To fit within envelope and meet fabrication considerations
Operating temperature	20±1° C nominal	Range is per allocation from SXT angular resolution error budget; minimizes angular distortions imposed by temperature change to components. Operating temperature is determined by optics assembly temperature
Mass	642 kg	Allocation (includes thermal collimators)

SXT Mirror Reference Concept

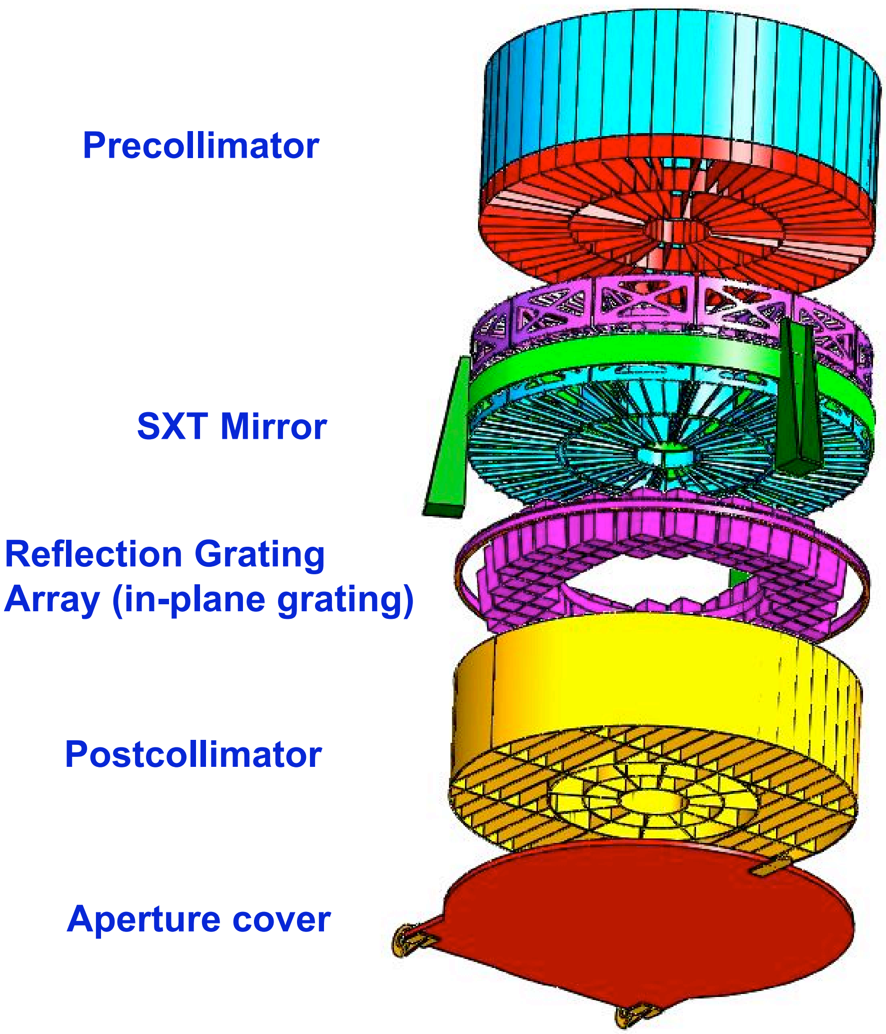
- **General Overview of Design**



SXT Mirror Reference Design Parameters

Parameter	Description
Design	Segmented Wolter I
Segment substrate material	Thermally formed glass
X-ray reflecting surface	Gold
Number of nested shells	127 (inner); 89 (outer)
Total number of segments	3660
Mirror segment length	20 cm
Number of modules	6 (inner); 12 (outer)
Module housing composition	Titanium alloy, CTE-matched to substrate
Module support structure	Composite
Largest segment surface area	0.08 m^2
Substrate density	2.5 gm/cm^3
Mirror segment thickness	0.44 ± 0.02 mm
Mirror segment microroughness	6 Angstroms RMS
FMA mechanical envelope	1.68 m dia x 1.98 m

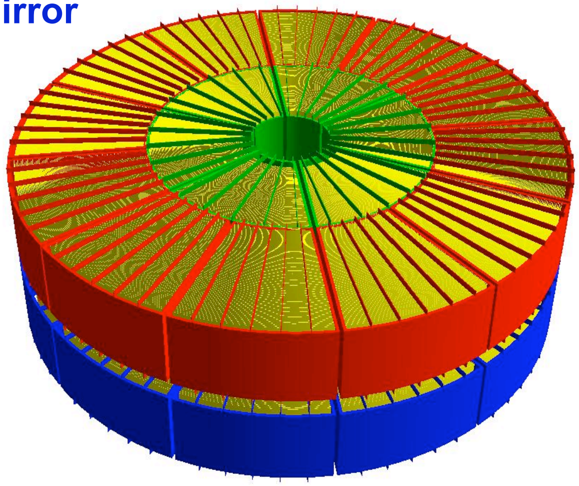
SXT Flight Mirror Assembly (FMA)



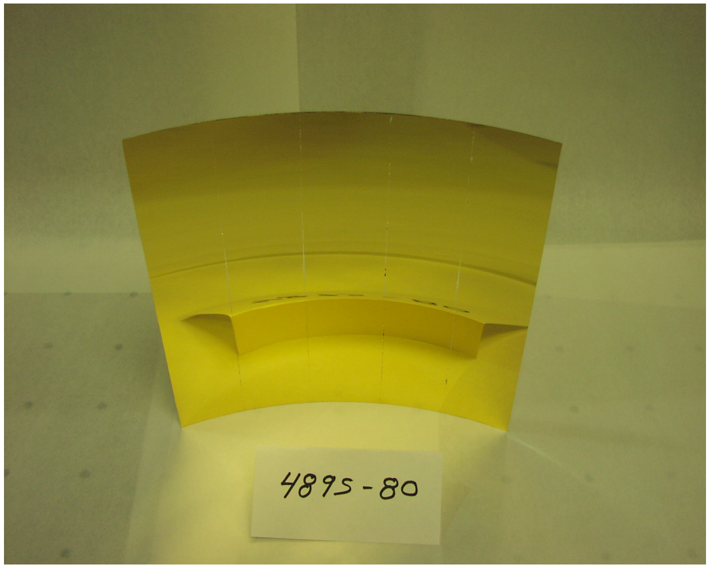
Elements of SXT Mirror Technology

- **Mirror segment fabrication process**
  - Thin, thermally formed glass substrates with gold overcoat
- **Precision-figured mandrel fabrication and metrology**
  - Forming and replication mandrels
  - Cylindrical and slab mandrels
- **Metrology for light-weight mirror segments**
  - Perform metrology with minimum distortion to segments

SXT Mirror



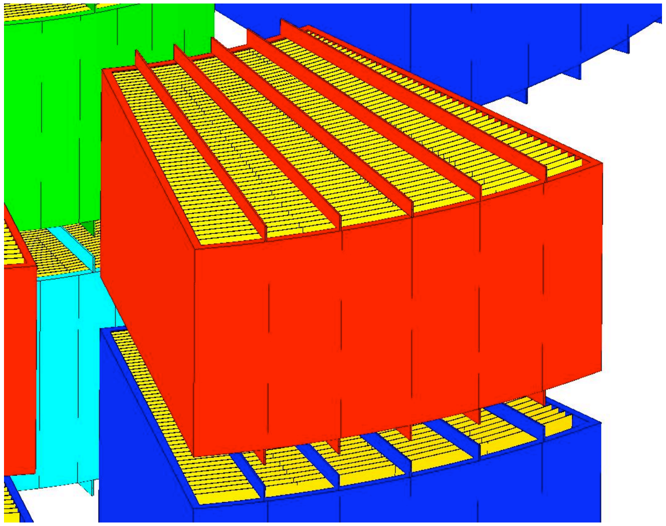
Mirror Segment



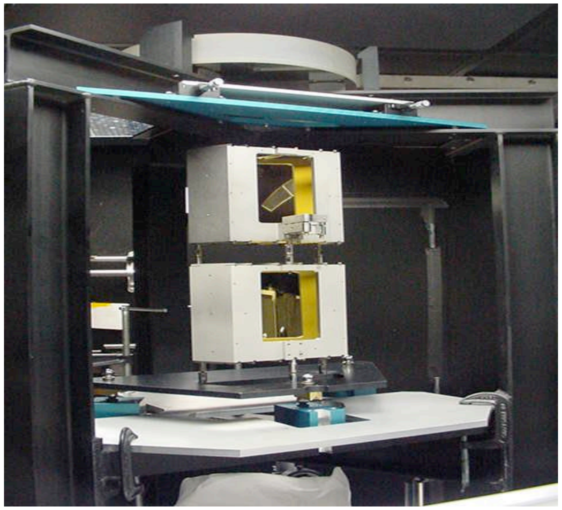
Elements of SXT Mirror Technology (cont.)

- **Alignment tools and techniques**
  - **Non-rigid body alignment with minimum figure error distortions**
  - **Mass alignment of multiple mirror pairs**
- **Mirror mounting and structural support**
  - **Minimum distortions to mirror segments**
  - **Facilitate alignment**
- **Mechanical properties of mirror segments**
  - **Mirror substrate (glass) strength**
  - **Glass thermal properties**
  - **Bonding to housing**
- **Technology must be transferable to industry for flight production**

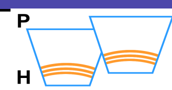
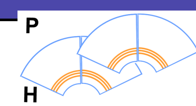
Highly nested segments



Alignment



Technology Development Roadmap Summary

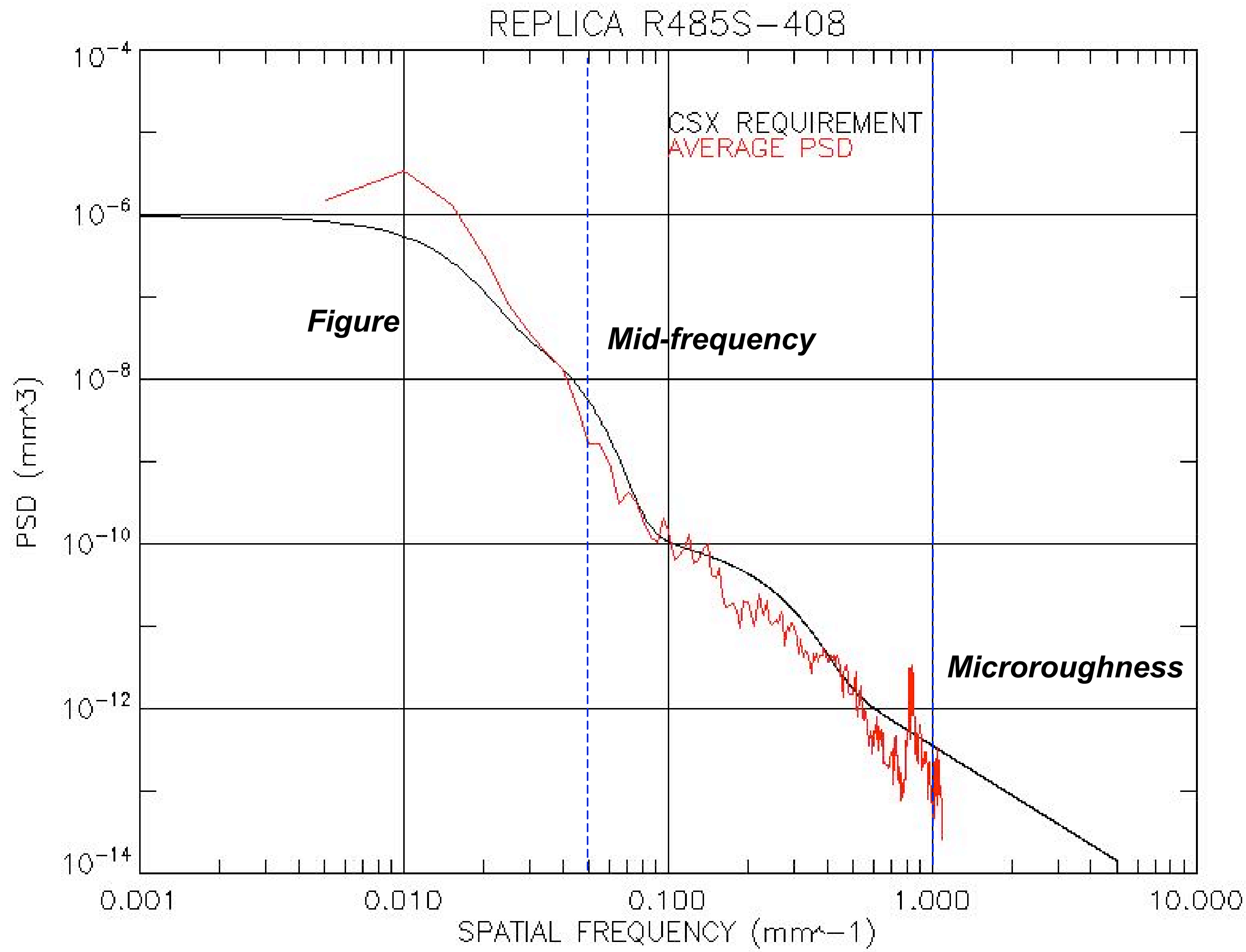
	Optical Assembly Pathfinder		Mass Alignment Pathfinder	Engineering Unit	Subassembly	
	OAP #1	OAP #2				
Configuration						
Module Type	Inner	Inner	Inner	Two inner modules	NASA Testbed – Outer + Inner	Industry Prototype – Outer + Inner
Housing Material	Aluminum	Titanium	Titanium	Titanium	Titanium	Titanium
Focal Length	8.4 m	8.4 m	8.4 m	10 m or 8.4 m (TBD)	10.0 m	10.0 m
Nominal mirror segment Diameter(s)	50 cm	50 cm	50 cm±	50 cm±	160 cm 120 cm± 100 cm, 50 cm±	160 cm± 120 cm± 100 cm±, 50 cm±
Goals	• Align 1 mirror segment pair (P&H) • Evaluate mirror assembly design, alignment and metrology	• Align 1 mirror segment pair • Evaluate segment performance and stability in mount • Evaluate mirror bonding • X-ray test • Vibration test	• Align up to 3 mirror segment pairs to achieve <12.5 arcsec • Evaluate tooling for mass alignment • Vibration & X-ray tests	• Fabricate segments from slab mandrels • Align module to module. • X-ray and environmental tests • Technology transfer to industry • Evaluate assy gravity sag	• Form largest mirror segments • Demonstrate reference subassembly design • Environmental and X-ray test	• Demonstrate flight prototype • Environmental and X-ray test • Industry build
TRL – Mirror segment	TRL 3	TRL 4/5		TRL 6		
TRL – Assembly	TRL 3	TRL 3/4	TRL 5	TRL 6		
Timeframe	Q2 of FY03	Q2 of FY06	2006 - 2009			
Technology Gate			u		u	

Mirror Segments - Technical challenges

We have a clear understanding of elements of producing mirror segments

- **Three largely decoupled spatial frequency domains**
  - Low order - 2-20 cm
  - Mid-frequency - 0.1-2 cm
  - High-frequency (microroughness) <0.1 cm
- **Low order**
  - Determined by forming; not improved by replication
  - Distortions due to gravity, mechanical stresses appear in this regime
  - Dictate forming mandrel requirements
- **Mid frequency**
  - Imparted to substrate during forming
  - Very sensitive dependence on physics of forming process
  - Very sensitive to presence of particulates
  - Corrected by epoxy replication
- **Microroughness**
  - Substrate material has excellent microroughness; preserved during forming
  - Replication introduces entirely new microsurface - this places requirements on replication mandrel microroughness (superpolishing is necessary)

Spatial Frequency Domains

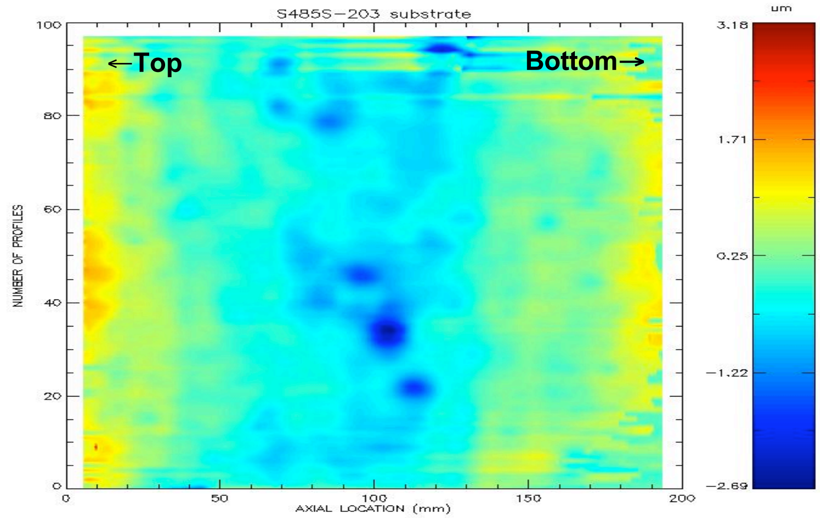


Mirror Segments - Recent Progress

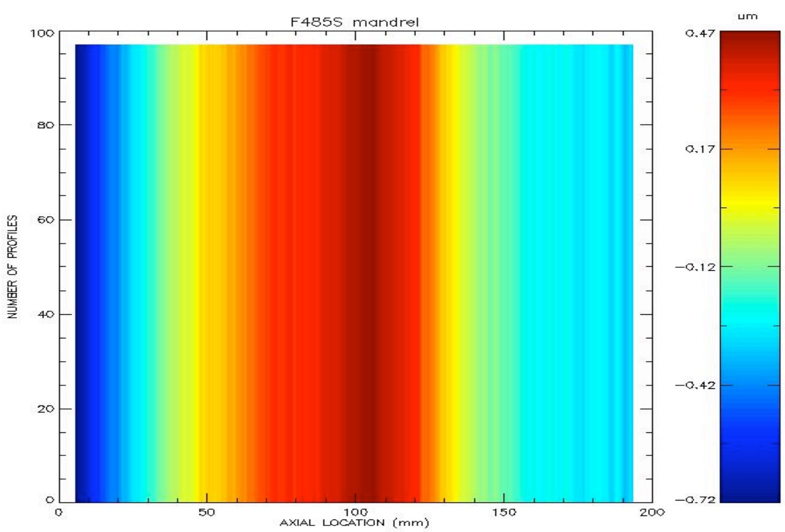
- Demonstrated that formed substrates faithfully and consistently reproduce the forming mandrel surface at low spatial frequencies
- Improved the formed and replicated mirror quality by reduction of size and number of particulates (dust) on surface
  - Invested considerable effort reducing environmental dust in mirror lab
- Demonstrated that replication with ~10 μm epoxy layer can smooth out mid-frequency errors without causing significant distortion to low order figure
- Demonstrated feasibility of producing mirror segments meeting the error budget requirement without replication
  - Low and mid frequency improvement is likely if more precise forming mandrels are used
- Demonstrated that low order figure distortions are very sensitive to segment orientation and how it is held
- Developed a forming mandrel release layer that is very smooth and durable, and reduces mid-frequency roughness introduced by forming
  - Possible to apply using robotic spraying (developed for epoxy)
  - Process improvements still being sought

2D Contour plot of recent substrate

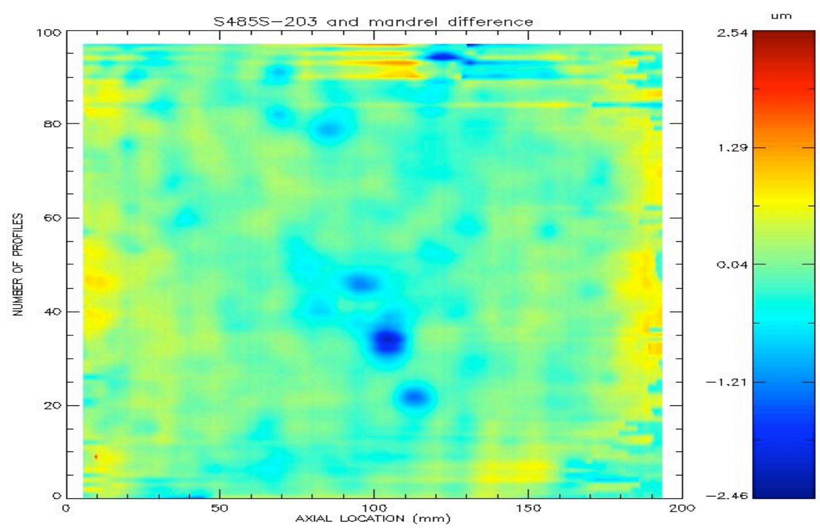
- **98 profiles measured; piston and tilt removed**
- **Single mandrel profile expanded to 2D**
- **RMS height error =0.30 μm**
- **Difference map represents <u>upper limit</u> of actual difference**
- **Large deviations due to dust particles**
- **Large deviation at top due to mounting fixture**



Measured profile (piston and tilt removed)

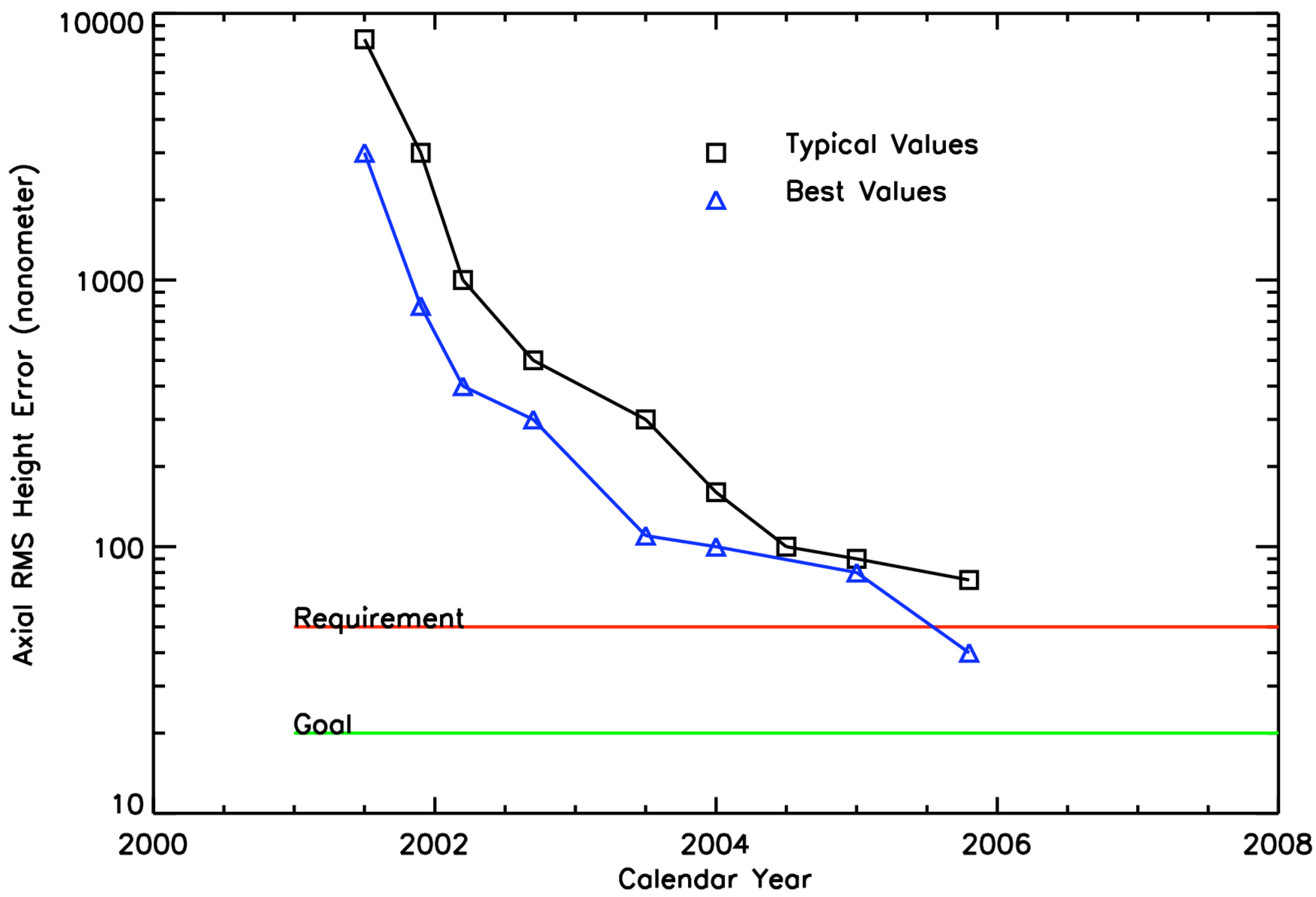


1D profile of forming mandrel



Difference between mandrel and substrate

Mirror Segment Figure Improvement



Mirror Segments - Challenges to Consistently Meeting Requirement

- Improvement of glass forming environment, including a clean/vacuum oven
- Better understanding of the surface physics of forming
- Ability to perform mechanical/thermal modeling of forming
- Improvement of the glass sheet cleaning process
- Better control of the epoxy replication environment: a mandrel coating chamber at GSFC
- Improved metrology of segment figure
  - Virtually impossible to measure free-standing segment, especially 2nd order sag
  - Such measurements are largely irrelevant - expect coupling between segment and mount (can't independently determine error budget terms)
  - We are building a 10-point mount to emulate conditions in housing, which facilitates 2D surface metrology

Mirror Segment Metrology Allocation vs. Measurement (ordered by HPD contribution)

Parameters	Units	Allocation	Status	Instrumentation	Plan/Comments
AXIAL FIGURE					
Slope	arcsec, rms	0.75	0.35	Interferometer	
Mid-frequency	nm, rms	2.53	0.5	Interferometer, Bauer200	
Micro-roughness	nm, rms	0.19	0.1	Microinterferometer	
Sag	µm, pv	0.04	_	Interferometer, MMTC	10-point mount will improve accuracy. Plan for better thermal control. Gravity back out model & verification required.
Delta-delta-radius	arcsec, pv	0.22	_	MMTC, Null lens	MMTC ∆∆R on mirror segment dominated by room thermal changes; Null lens needs permanent mount & calibration.
Roundness	µm, pv	1.58	3.5	MMTC	Dominated by room thermal changes (range during test from 2.7µm to 3.5 µm). Plan for better thermal control.
Cone-angle	arcsec	3.16	_	MMTC	Optipro/MMTC. 10-point mount will improve accuracy. Plan for better thermal control. ±0.65 arcsec measured on solid calibration cylinder.
Average radius	_m	10.4	_	MMTC	Optipro/MMTC. 10-point mount will improve accuracy. Plan for better thermal control. ±1.8 µm measured on solid calibration cylinder.

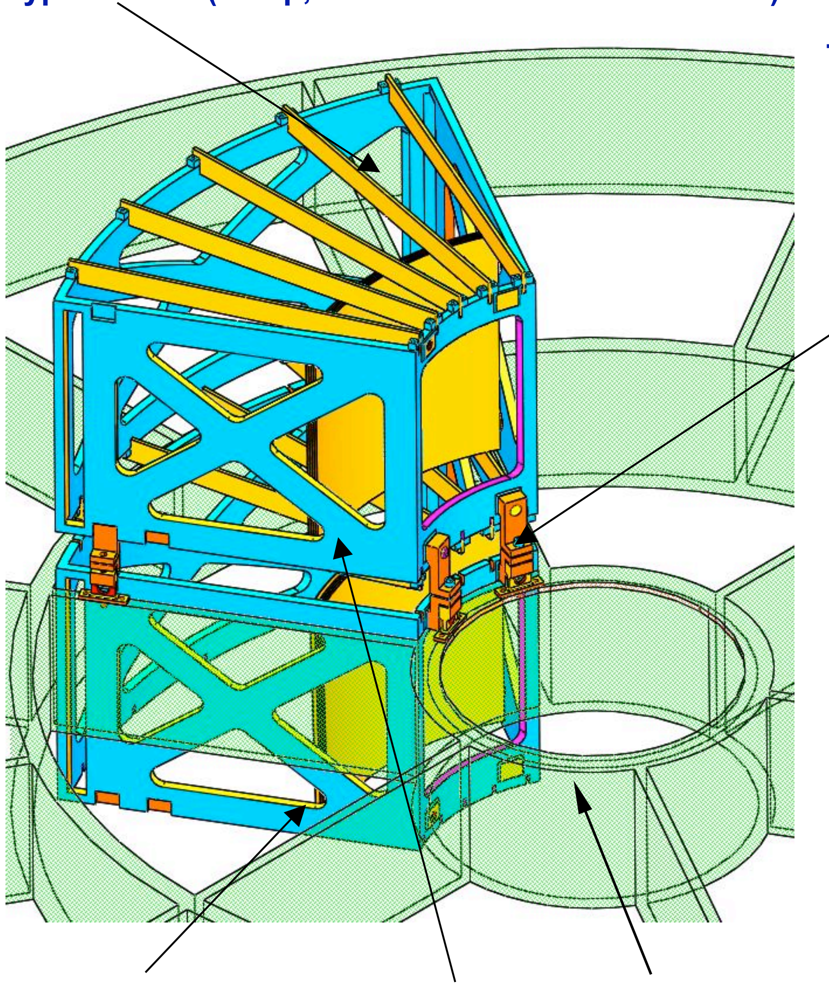
Metrology - Recent Progress

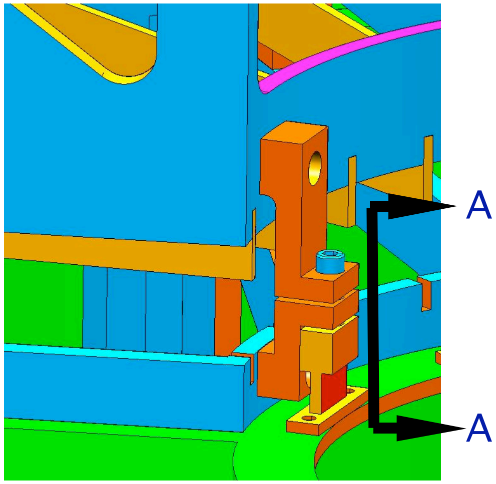
- **Demonstrated that Centroid Detector Assembly (CDA) designed for Chandra mirror alignment can be used to align mirror segments – purchased upgraded CDA**
- **Improved metrology techniques for measuring segments**
  - **Validated interferometric axial profiling technique**
  - **Confirmed optical microroughness metrology provides a precise prediction of mirror segment X-ray scattering**
  - **Designed and procured a cylindrical null lens for axial metrology over the full height by 2/3 width of segment**
  - **Obtained equipment to perform metrology with minimum distortions to segments**
  - **Introduced non-contact cylindrical Coordinate Measuring Machine (CMM) - measures cone angle, radius, and low-order figure without touching the part**
- **Reduced the vibration sensitivity of measurements**
  - **Completed modeling and measurement to establish the need for vibration insensitive metrology and/or better mechanical isolation**
  - **Vibration robust, full-aperture interferometer is nearly ready for delivery**
  - **10-point mount design reviewed and in work (will alleviate vibration & thermal drifts)**
  - **Plan for better lab environment control**

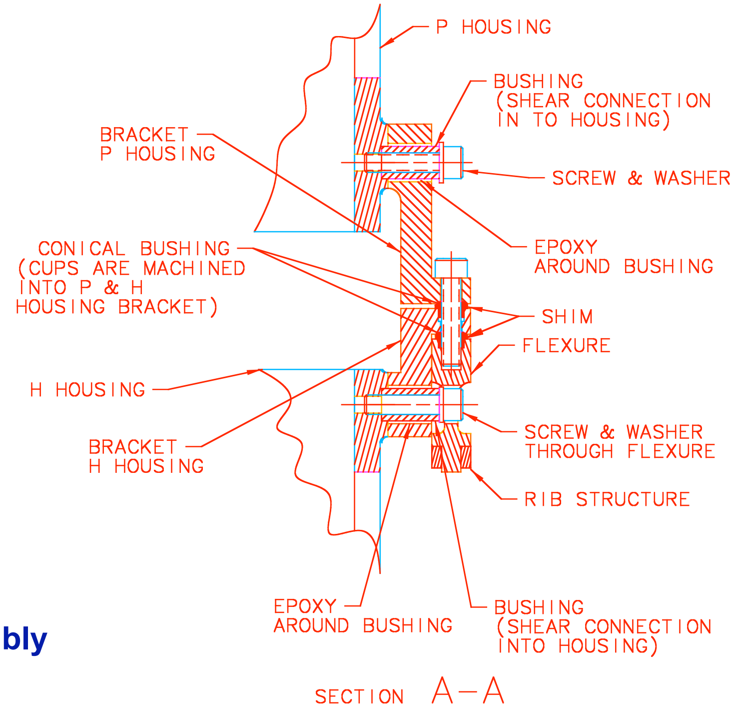
Reference FMA Concept

- **Typical Primary/Secondary (P/S) Module Stack up:**

This concept uses flexures to attach the P and S sub-modules together, as well as, to the Ring Structure Assembly

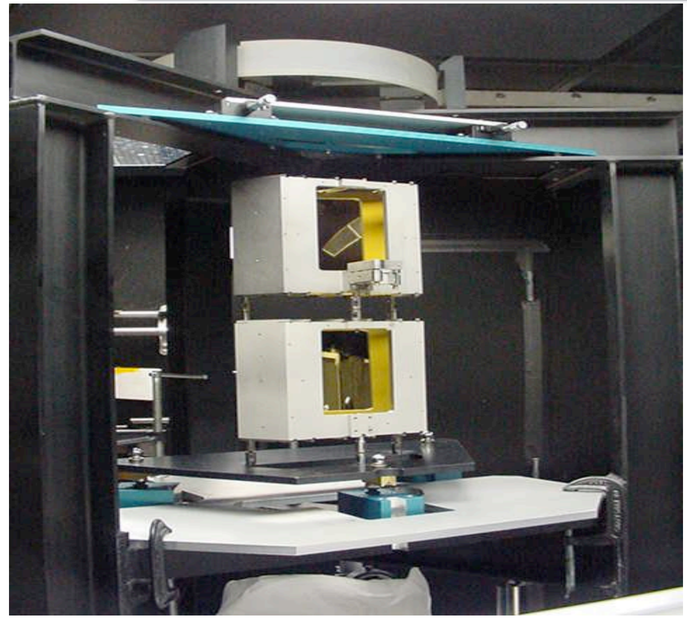


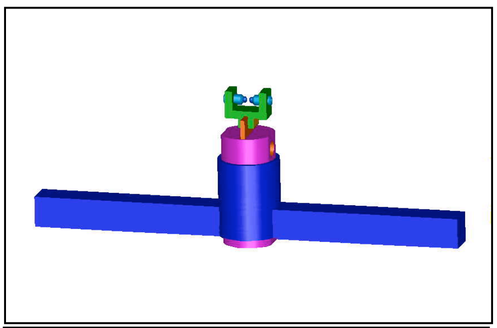


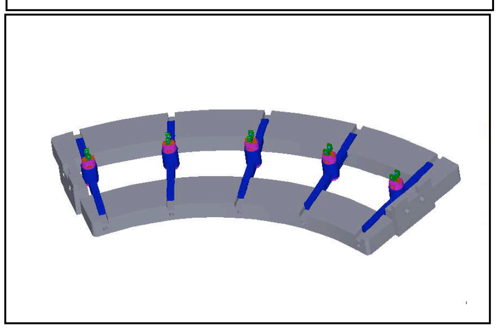


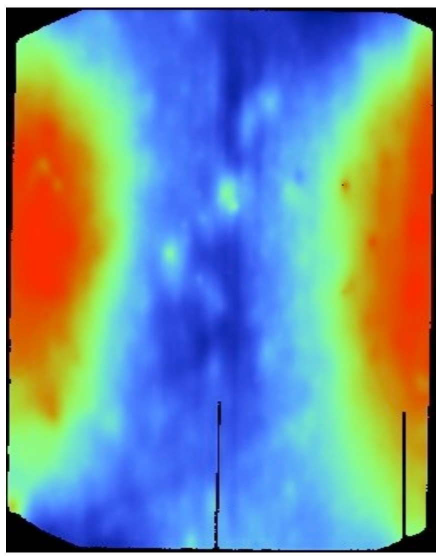
Segment Alignment

- Developed an alignment technique using CDA and in-situ interferometric monitoring of mirror figure
- Demonstrated the ability of piezoelectric bending actuators to align a single secondary mirror using CDA feedback
- CDA: RMS diameter of 4.35 arcsec in the focal plane based on 12 positions across the mirror segment
  - Developing alignment procedure



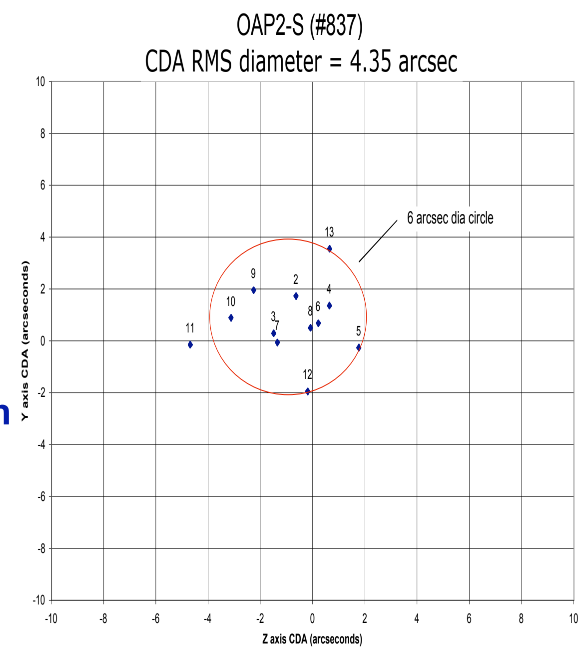






95 mm out of 200 mm height

27 deg out of 50 deg azimuth



Plans for Coming Year (and Beyond)

- ***Mount and align one or more pairs of mirror segments***
  - *Perform in situ full surface metrology within OAP2 mout*
  - *Demonstrate that aligned segments meet the Constellation-X HPD requirement*
  - *Quantify residual errors to determine most significant contributions*
  - *Compare 3D segment surface measurements and distortions (using special metrology mount) with optical and mechanical models*
- ***Verify performance of aligned mirror pair(s) in X-rays; compare with predictions from metrology***
- ***Continue development of alignment procedures***
  - *Introduce next generation Piezo actuators*
  - *Integrate collimated beam, surface profile interferometry, and CDA*
- ***Refigure forming mandrel pair to allow 3 arc second HPD (Con-X goal)***
- ***Procure and test 50 cm "slab" forming mandrel***
  - *Couple with thermo-mechanical modeling of forming process*
  - *Initiate conversion of forming to "flight-like" mandrels*
- ***Involve industry in studies of Flight Mirror Assembly and mandrel fabrication***
  - *Mandrel fabrication is critical path of the program - need to identify multiple suppliers*
  - *Mounting process could benefit from independent engineering study*
- ***Support project efforts to reconfigure Con-X and approach performance goals***
- ***New funding reductions will significantly delay all mirror technology development, and could result in irretrievable loss of knowledge***

Summary

- The current forming technique produces substrates of consistent quality, approaching the Con-X requirement.
- Epoxy replication might not be necessary.
- Our knowledge of the mirror performance is limited by primarily metrology fixturing.
- The mirror performance is limited by mandrel quality and contamination
- We have means of performing all necessary diagnostic metrology of mirror substrates.
- We have a refined approach to aligning and mounting mirror segments, incorporating piezoelectric actuators and additional steps.
- Aligning a good segment pair to within the Con-X requirement should be possible using the current approach.